CERCA'S EXPERIENCE IN UMO FUEL MANUFACTURING

25th International meeting on RERTR
Chicago, United state of America

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ABSTRACT

Considered as a suitable solution for non-proliferation and reprocessing purposes, UMo fuel has been chosen and studied by the RERTR program since 1996. Involved in the RERTR fuel developments since 1978, with more than 20 years of U_3SI_2 fuel production, and closely linked to the French Commissariat à l'Energie Atomique, CERCA was able to define properly, from the beginning, the right R&D actions plan for UMo fuel development.

CERCA has already demonstrated during the last 4 years its ability to manufacture plates and fuel elements with high density UMo fuel. UMo full size plates produced for 4 irradiation experiments in 3 European reactors afforded us a unique experience.

In addition, as a main part of our R&D effort, we have always studied in depth a key part of the CERCA process outline which is the plate rolling stage. After some preliminary investigation in order to define the phenomenological model describing the behavior of the fuel core when rolling, we have developed a rolling digital simulator.

1. INTRODUCTION

Due to its intense involvement for many years in developing the production of an UMo uranium-based alloy fuel, CERCA now has unique feedback on the design and manufacture of this type of fuel.

This experience is first of all the outcome of a constant, beneficial collaboration since 1999 with the main actors in the French nuclear field dealing with the world of research reactors (CEA, COGEMA and Framatome ANP).

A complete irradiation programme is underway, the aim of which is the validation of the behaviour under irradiation of a high density (8 gU/cm^3) U-7%Mo fuel. This programme is based on limiting experimental conditions and concerns the irradiation of full size plates and elements thereby conferring an industrial perspective on our approach.

Thus, more than 13 UMo plates manufactured by CERCA have been irradiated or are being irradiated in connection with this programme [1],[2]. Two fuel elements are scheduled for irradiation in 2004. This unique feedback also integrates the definition of criteria which are defined in the specifications in collaboration with each reactor (OSIRIS, BR2 and HFR).

Independently of this and in order to answer a need specific to the reactor R2 at STUDVIK, CERCA has successfully manufactured in 2002 the first UMo fuel element, thereby creating a world first [3].

Through the manufacture of this element the safety aspects at element level have been solved and the first data connected with plate production on a larger scale have been obtained. The problems involved in transporting a new type of fuel have also been solved.

In the first part of this paper, the results obtained from all our UMo productions are presented in a synthesis. Precisions concerning our inspection procedures are presented and enable the relevance of the improvements implemented to be checked.

In the second part, the results obtained from a modelisation study of the fuel plate rolling is presented. These results are the fruit of numerous years of research carried out in collaboration with a French universitsy laboratory.

2. EXPERIENCE IN UMo FUEL PLATE MANUFACTURING

The main manufacturing data and irradiation conditions for the first UMo plates irradiated in OSIRIS and HFR which were manufactured in 1999 are presented in [4].

The origins of the rupture observed on the U-9Mo plate with a fuel enriched to 35% during the UMUS experiment in HFR are presented in [5]. The investigations and analyses conducted on this rupture have not revealed causes connected with manufacturing aspects.

The good behaviour of UMo fuel during the OSISIS 1 experiment and the results of the PEI examinations of irradiated plates are presented in this conference.

In 2002, two new series of UMo plates have been manufactured [6]. The experimental conditions pertaining during the irradiation of UMo plates in the reactor BR2 (FUTURE experiment) and OSIRIS (OSIRIS II experiment) are presented also in this conference.

This year, as a support to the UMo qualification programme in collaboration with ANL and ANSTO, two complete elements with a density higher than 7 gU/cm^3 will be manufactured by CERCA. These elements are scheduled for irradiation in 2004 in the CEA reactor OSIRIS.

2.1. UMO POWDER MANUFACTURING

In addition to the R&D efforts implemented which are aimed at mastering important stages in the manufacture of plates (homogenisation, compacting, rolling, etc), CERCA is pursuing its programme of study in connection with the manufacturing of UMo powder.

This programme concerns the evaluation of the production processes (economic, safety and industrial aspects), the intrinsic characterisation of powders and mainly the potential impact of UMo particles on finished products (compatibility of the manufacturing process outline, impact on the inspection criteria).

Our experience today involves two types of UMo powder. For the first series of plates manufactured in connection with the FUMOG (French UMo group), UMo obtained by the traditional method of crushing was used.

The second series and the R2 element were made using spherical UMo powder obtained by atomisation. Other manufacturing processes are being studied.

The behavior of the UMo fuel under irradiation, which is linked to the intrinsical propreties of the particules [7], will finally guide the manufacturing processe choice.

2.2. MANUFACTURING RESULTS

2.2.1. Destructive examination

The meat and cladding thickness are measured by destructive examinations in two individual areas, the working part and the ends, respectively.

In short, UMo Spherical powder is compatible with our advanced process and the dog-bone effects are attenuated by the use of this type of powder. This fact is the result of the fuel material flowing better during rolling.

2.2.2. Homogeneity of U distribution

Before an analysis is made of the results obtained on the UMo fuel plates, the inspection procedures to check homogenity will be described below.

The homogeneity of Uranium distribution is quantitatively inspected by means of a radiographic system with X ray spot that scans the length of the plate. The uranium density is determined by measuring the absorption of the beam.

The X-ray spot is converted into a digital signal by a linear X-ray detector called a CCD (Charge Coupled Device) which works as follows : the X-ray flow is converted into a photon flow which can be seen on a scintillator, which in turn is converted into an electrical signal by photodiodes. The signals are then multiplexed and converted into a digital signal.

The direct processing of the signal, without using an intermediary transfer support, like a film, for example, enables uncertainties to be minimalised, including human error during acquisition or analysis. With a reduced acquisition time, a complete map of the objects inspected is obtained and an automatic scan of irregularities by zone is made.

Since the manufacture of the first UMo plates, a significant improvement in homogeneity results has been obtained. This improvement is linked mainly with our latest advanced process development. In parallel, the atomized UMo powder enables local lopping of some irregular interface shapes between the fissile core and the cladding frame.

The homogeneity average is then controlled by the CERCA process when the local response is optimized with atomized UMo powder.

As a function of the manufacturing process itself and the material used, homogeneity results will be optimized. Some studies are under way in order to improve the UMo/Al powder mixing step as well as the rolling procedure. Improvements connected with the reproducibility of homogeneity are expected for our future production. As a key part of this dedicated study, our accurate inspection system will be used in order to get the right information needed.

2.2.3. Inspection of Stray fuel particles

To avoid any increase in local temperature and the release of fission products in some particular plate areas during irradiation, the stray particle specification has to be well defined. This is very sensitive with high density fuels. Then, depending on customer specifications, plates are acceptable or rejected. According to our long experience, many manufacturing parameters impact the presence of free particles.

From the powder type or the compaction procedure to the rolling stage, the stray fuel particles which can be seen by examination of properly exposed X radiographs, are, statistically speaking, very difficult to avoid.

Spherical UMo powder challenges the control of this type of effect. However, experience enabled to produce plates that were acceptable to our customers

2.3. CONCLUSION

After the first manufacturing experience in 1999 including Mo variability contents and different enrichment values, a significant batch of UMo full size plates with a density from 7 gU/cm^3 up to 8 gU/cm^3 have since then been manufactured at CERCA. Our experience has gone from an R&D

stage to a preliminary industrialisation stage, which has enabled us to understand and solve numerous difficulties (technical, safety, transport, etc)

Generally speaking, all aspects of manufacture have been dealt with, solutions found and satisfactory results obtained.

Concerning UMo powder production, CERCA is testing all types of UMo powder in order to obtain a global view of these topics. A further investigation of a specific device for UMo powder production is being investigated. Preliminary results will be obtained in 2004.

Within the framework of the world wide qualification program of UMo fuel, the fourth quarter of 2003 is going to see the production of two new UMo fuel assemblies with a density of 7 gU/cm^3.

3. NUMERICAL ROLLING SIMULATION

A crucial phase in the manufacture of fuel plates, rolling is a delicate step which directly influences the intrinsic quality of the product (dimensions, homogeneity, cladding thickness, etc). Being governed by multiple thermo-mechanical phenomena, rolling is therefore a science in its own right.

Depending on the degree of maturity of individual organisation and technical know-how, two approaches enable the rolling stages to be mastered.

The first is empirical and is based on experiment. An intermediary phase consists of accessing a fine knowledge of the influencial parameters by making use of data acquired during an instrumentation run during the manufacturing process.

The correlation of the measurements with the results recorded on the plates enables these phenomena to be understood and the quality of the product to be followed by monitoring the process (SPC approach; Statistical Process Control)

CERCA, for example, ensures follow-up of successive rolling passes and drift is anticipated (minimalisation of the effect of scale and strong reactivity).

Furthermore, preventive maintenance actions have been the direct result of this approach: maintenance activities are optimised and the life expectancy of the industrial tool prolonged.

The second approach is based on a digital simulation. With this approach, a powerful investigatory tool is available and enables the influence of such and such a parameter on the final quality of plates to be tested straight away without taking up too much time.

This option involves modelling fuel core behaviour during deformation. The use of ad hoc software using finit element will then provide access to the final results.

The knowledge of the elasto-plastic behaviour laws of the contacting materials subjected to the mechanisms to the cold and hot deformation mechanisms during rolling is therefore the first difficulty.

An example of such behaviour law is the well known Von Mises law (constant shearing strain whatever the hydrostatic pressure)

During the experimental part, a lot of classical tests have been conducted on the materials.

Another particulary plane strain test has been specially developed for this study which is very interesting for modeliling rolling. By means of the different tests, a new law has been deduced taking into account the compressibility of the materials.

The initial temperature, the rolling pass, the reduction, the charge quantity are included in the model and the different influences exerted by them have been analysed. This preliminary phase took over 18 months

This modelling could be used to simulate the behaviour of the material using software. Various types exist and are used to simulate different behaviour.

The issue here is to obtain a numerical convergence of the software in a complex description. First, the Von Mises law has been introduced. Then, the new model has been also introduced. Finally the last stage consists of validating the results obtained based on real production runs and defining the limits of use.

Then, some simulations could be carried out to predict the outcome of rolling by playing around with different parameters such as initial temperature, different reduction, quantity of hard phase, different cumulated plastic strain. Each parameter change could be anticipated thanks to simulation.

Figure 1 shows a longitudinal section of a fuel plate during the hot rolling step. In this example, the strains are properly distributed between the support and the fuel meat. The fuel core is deformed and the formation of a dog-bone is anticipated.

4. CONCLUSION

To develop a new fuel requires a lot of technical resources, a clear vision of the development program and constant effort to reach the aim of qualification. For the UMo, qualification is scheduled for 2006.

That is why, in the French UMo Group, CERCA has constantly steered a course towards the development program since the early schedule presented in 1999. All valuable technical options are being considered to ensure that the right choice is made regarding the industrial scale.

In 2002, for the first time, a U-7Mo lead test assembly for R2 reactor was manufactured by CERCA.

Thanks to the plates which are under irradiation, the UMo specification will be finally adjusted in order to highlight the main parameters and associated range which needs to be determined.

However, being ready from a technical point of view is necessary, but not sufficient. The fuel business has a long time constant.

We have to submit our projects to safety authorities, and so, many things must be anticipated as far as industrial production is concerned. From that point of view, CERCA is launching, in parallel, a further industrialization program taking into account the whole production processes up to fuel shipment.

The aim is to offer in 2005 a stabilized, qualified, licensed and cost effective fuel production process.

Results coming from a digital rolling simulation study have been obtained and presented by CERCA for the first time. An elasto-plastic model of the fuel meat was determined taking into account the compressibility aspect of the material used. Some adjustment of the software is being addressed and final results are expected in 2004. After the validation stage, CERCA will have a new investigation tool which will allow us to improve our knowledge of the rolling part of our process flow outline.

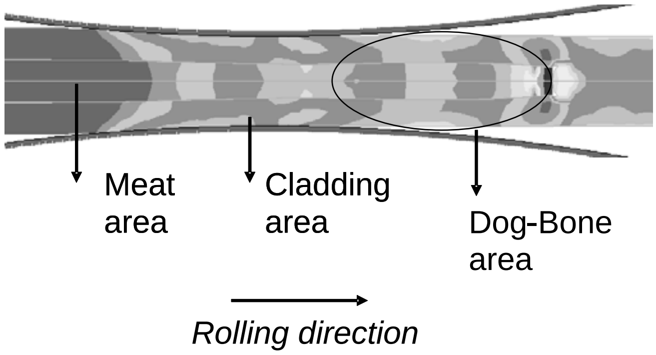

Figure 1: Digital simulation during the first hot rolling pass schedule.

5. References

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